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The High Latitude Ionosphere-Magnetosphere Transition Region: Simulation and Data Comparison

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Summary of Project Activities

Below is a brief description of the major activities for this grant during the last three years.

1. Model Development. Much of the work in this project has been facilitated by the development of a generalized semikinetic (GSK) model capable of treating the ions kinetically from altitudes deep in the ionosphere out to the magnetosphere. A number of ion-neutral collisional and chemical processes were included in the model. These included ion-neutral polarization and resonant charge exchange collisions between O^+ and atomic oxygen and polarization collisions with N_2. The technique used to include these collisions is basically the same as that of *Barakat et al.* [1983]. Chemical loss of O^+ through the energy dependent reactions with O_2 and N_2 was also added through the use of a Monte Carlo technique similar to the collision processes. The cross sections used were those of *Albritton et al.* [1977]. The method was shown to be valid since it was able to give the correct reaction rates for O^+ reacting with O_2 and N_2 as a function of relative temperature for Maxwellian velocity distributions. The accidentally resonant charge exchange reaction between O^+ and H was included using the cross section given in *Banks and Kockarts* [1973]. Photoionization and electron impact ionization of atomic oxygen was added as an altitude dependent production process, introducing simulation particles at the appropriate rate with velocities drawn from a Maxwellian with the exospheric temperature. Collisions between ions and electrons have also been added through the use of the method of *Takizuka and Abe* [1977] similar to the way other Coulomb collisions have been handled. Initially the model described a region from 200 km to 1200 km. Later it was extended to an altitude of 1 Re and then to 3 Re. These later extensions required special techniques for handling the O^+ ions because of the often large decline in its density over this altitude range. The important macroscopic forces (gravity, magnetic mirror, ambipolar electric, and centrifugal) were all included in the model. The centrifugal force becomes very important at high altitudes for moderate to strong convection field strengths.

2. $\mathbf{E} \times \mathbf{B}$ *Convection Heating Study.* The first area to which the above described model was applied was a study of the development of O^+ upflows generated by episodes of strong $\mathbf{E} \times \mathbf{B}$ convection in the high latitude ionosphere. When such convection occurs the ions can flow through the neutrals at supersonic speeds. Ion-neutral collisions will heat the ions perpendicular to the magnetic field and produce toroidal velocity distributions. Ion self collisions and ion-neural polarization collisions will scatter ion velocities so that much of the perpendicular velocity will become parallel velocity and create large O^+ upflows. From this study we found that the toroidal O^+ velocity distributions that develop at low altitude give way to triangular shaped distributions at intermediate altitudes above the region where ion-neutral collisions are important. These develop as a consequence of the ions, perpendicularly heated at low altitudes, trying to form a conic distribution at these intermediate altitudes but not being able to because of the tendency to relax to an isotropic distribution due to Coulomb self collisions. During episodes of strong convection ($E > 150$ mV/m) a significant number of O^+ ions can be energized to the point where they become collisionless and can free stream out of the ionosphere. One then sees O^+ velocity distributions with upward directed suprathermal tails at 1100 km and above.

3. Extension of the $\mathbf{E} \times \mathbf{B}$ *Convection Heating Study to include centrifugal effects.* With the extension of the GSK to higher altitudes it was possible to study the combined effects of low altitude $\mathbf{E} \times \mathbf{B}$ convection heating and centrifugal acceleration. In this study we found that even moderately high levels of convection ($E \leq 100$ mV/m) can lead to large increases in the densities of O^+ in the polar ionosphere. After an increase in the convection speed two large O^+ upflows will be seen, one resulting from the centrifugal acceleration and the other resulting from the low altitude frictional heating. Regardless of whether the convection speed is increased and held constant or pulsed, down flowing ions are seen several 10's of minutes later, some distance from the point where the convection first changed. Often, O^+ counterstreaming distributions are seen when downfalling ions from early in the process fall through upflowing ions energized later or at lower altitude. At intermediate altitudes (1000-4000 km) the H^+ velocity distribution can be greatly modified during periods of enhanced convection even though it is not greatly affected by centrifugal acceleration at these altitudes or frictional heating at low altitudes. This results because of the changes to the O^+ population (increased densities and drift speeds) that affect H^+ because of its strong collisional coupling to O^+.

4. Study of energetic electron precipitation The purpose of this study is to see what effect energetic electron precipitation has on the O^+ and H^+ ions in the topside transition region. The model mentioned in *1* above was used along with a two stream electron code developed by P. Richards. At present the model only includes the ionization effects of these electrons and not there effect on thermal electron temperature. In this on going project we have found enhanced ionization resulting from soft electron precipitation increases the O^+ pressure in the F-region and drives a modest O^+ upflow. Generally the velocity distributions remain close to Maxwellian as might be expected. We anticipate that when electron heating is added the model will show some interesting results.

5. Polar Cap Data-Model Comparison We conducted a study to compare polar cap velocity distributions for the light ions H^+ and He^+, with model results. The data are from the DE-1 RIMS instrument and are samples collected in the polar wind acceleration region (1500–4000 km) and above, at magnetic latitudes greater than 75°. The data set is an extended version of that used by *Chandler et al.* [1991] to study the polar wind. Comparisons were made between the model and data for H^+ and He^+ density and drift speed. (He^+ and its associated chemical and collisional processes where added to the model for this study.) The largest discrepancy between the two was for the H^+ drift speed, with the model giving speeds twice as large as the data on average. All efforts to reduce the model H^+ drift speeds in the steady state model results by changes in the electron temperature profile and the O^+ densities were unable to improve the comparison. One possible explanation is that there develops a partial potential barrier to H^+ outflow above 1 Re altitude. Another is that the O^+ in the polar cap often possesses a relatively large upward flow speed so that it will exert a stronger collisional drag on the H^+.

The skew of the RIMS radial head spin curves (counts versus spacecraft spin phase) can be an indication of heatflow. We have done some statistical analysis of these skews for the low altitude polar cap data and find trends which appear to indicate a consistent process is operating. We performed a number of simulation runs for comparison with this data matched to the conditions of the data as much as possible. We found that the model can produced H^+ velocity distributions which give skewed spin curves (when passed through a RIMS instrument simulation filter) but the data often shows more skewing than the current model can explain. It may be that the greater skewing of the H^+ spin curves is related to the lower parallel drift speeds. Both can be explained by the potential barrier mentioned above.

6. Study of wave heating of O^+. During 1994 a graduate student (D. Gristina) began a study of the consequences of O^+ wave driven heating that occurs at altitudes where collisions are important. The waves are produced by precipitating electrons with unstable velocity distributions and are assumed to be the same process that results in the lower hybrid spiklets. To test our procedures we initially did a series of local calculations that showed that perpendicular heating at low altitudes by lower hybrid waves can produce X shaped distributions (with the arms of the X in the perpendicular and parallel directions) with large numbers of ions with field-aligned velocities in both the upward and downward direction. We continued this study to include transport effects by developing a hybrid model which treats wave heated O^+ ions kinetically as particles while the core unheated ions are described as a fluid. Results of studies with this model have shown that the X distribution can lead to strong ion upflows at early times in the heating event as long as the heating occurs at 800 km or below. Hybrid Maxwellian-conic distributions develop at altitudes above 700 km. We have also seen downward conics at altitudes below where heating occurs. At the present time D. Gristina is finishing up his master's thesis.

7. Study of Photoelectron Effects. Recent work on the effect of photoelectrons on plasma outflow at high latitudes [*Tam et al.*, 1995] has suggested the possibility that the energy flux of these electrons is sufficient to produce large outflowing fluxes of O^+ ions. In their results [*Tam et al.*, 1995] the O^+ ions are accelerate to supersonic speeds at altitudes below 600 km and the electrons are heated to temperatures in excess of 40000 K at 1000 km. We have reexamined this problem to look for steady-state solutions which do not produce such large effects at low altitude. Any solution to this problem must satisfy the conditions of charge neutrality and zero current. The *Tam et al.* [1995] solution achieves a zero current by balancing the flux of photoelectrons with the O^+ ion flux. We have found solutions which balance the upward photoelectron flux with a downward flux of thermal electrons. Such solutions do not produce large fluxes of O^+ ions which remain subsonic to at least 4000 km altitude. Thermal electron temperatures do increase with altitude to 20,000–50,000 K but such increases occur above 2500 km altitude and result in an electric field that produces a potential drop of only 5 to 6 V between 500 and 19,000 km altitude. Figure 1 shows a sample of these results. These and other results will be presented at the upcoming spring AGU meeting.

8. Study of Molecular Ion Outflow. As has been recently pointed out [*Peterson et al.*, 1994] the observation of outflowing molecular ions (N_2^+, NO^+, and O_2^+) has a number of profound implications for ion energization processes. These process must either effect the ionosphere to low altitudes or act in concert with other process that do. The also must heat molecular ions rapidly so that they can escape from the ionosphere before they are lost to dissociative recombination. We have begun a review of the DE-1 RIMS observations of molecular ions to see what they can tell us about these questions. There exist many time intervals (> 50) when these ions are observed, many of them at low altitude. The low

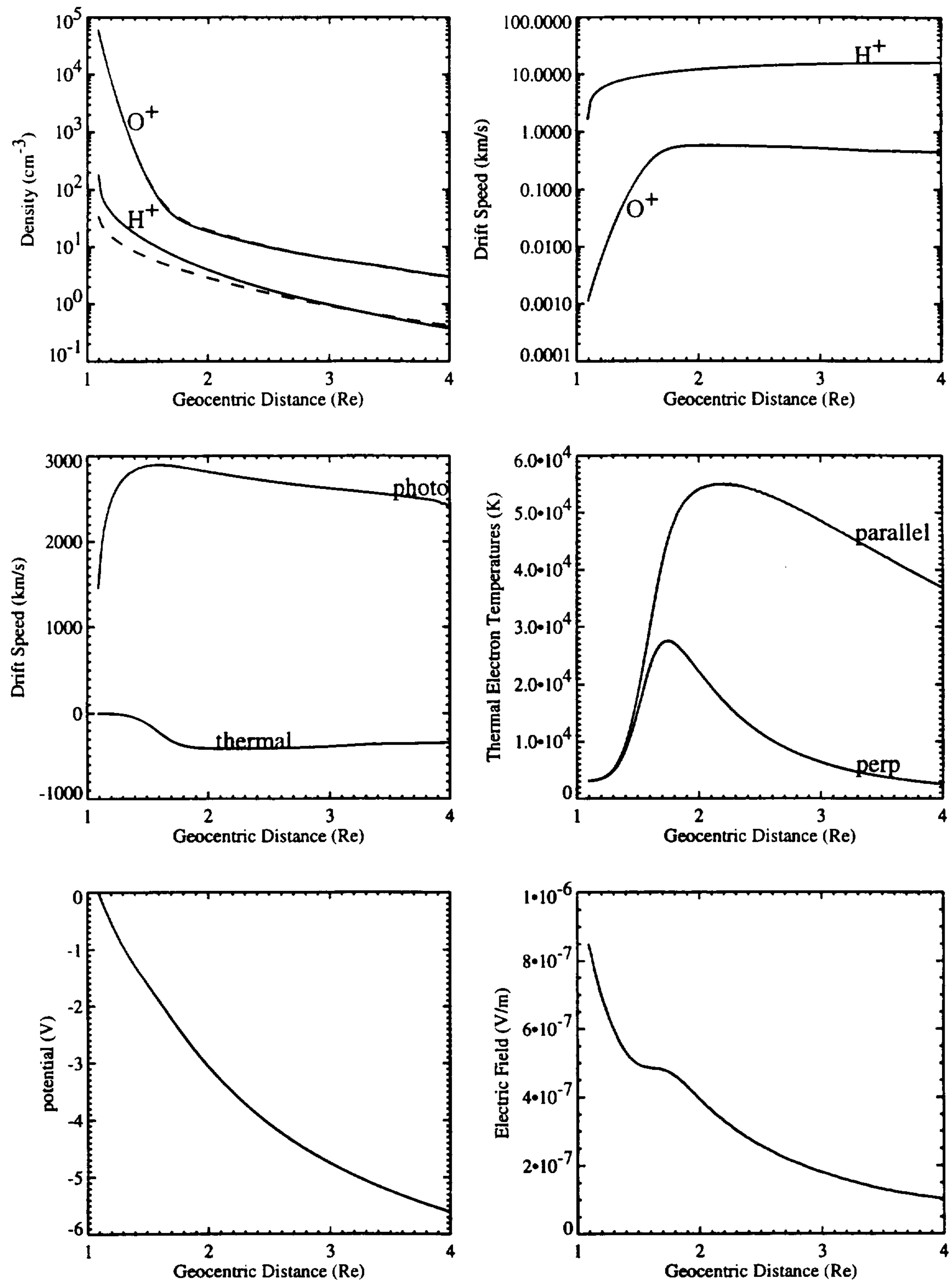

Fig. 1 Steady state results for the effect of photoelectrons on high latitude ion outflow. The first panel shows ion (solid) and electron densities (dashed). The lower of the two dashed curves is the photoelectron density. The third panel shows the photoelectron and thermal electron drift speeds.

altitude cases are particularly important because they are made very close to the source location and is possible that one will observe the causative agent along with the ions. In a review of a number of these cases I see evidence for strong convection and field-aligned currents where the molecular ions are seen. We are currently preparing to use our model to simulate this situation. Results of this work will be presented at the upcoming spring AGU meeting.

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